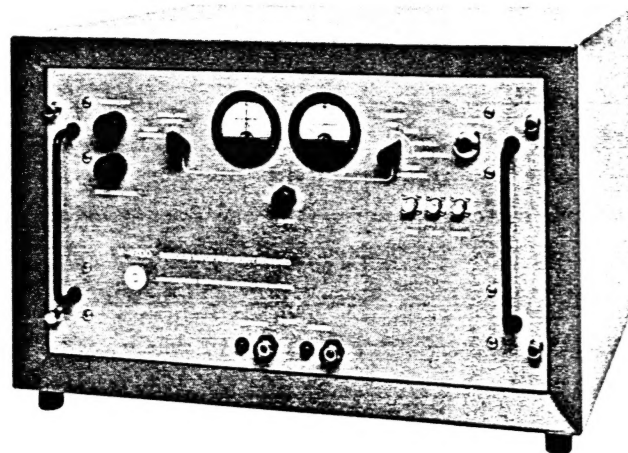


The natural invariant physical reference which makes possible the degree of accuracy and stability achieved by the Varian Model V-4700A Rubidium Vapor Frequency Standard is the  $Rb^{87}$  ground state hyperfine transition of 6834.69... mc. The Rubidium Vapor Frequency Standard utilizes the principles of optical pumping and transmission monitoring to couple the output frequency to this physical atomic reference.

Optical pumping selectively removes rubidium atoms from the optically opaque lower hyperfine ground state and transfers them to the optically transparent upper hyperfine ground state, resulting in an overpopulation of the transparent state. By subjecting the atoms in the overpopulated state to a microwave magnetic field whose frequency corresponds to the hyperfine separation, transitions are induced back to the opaque optical state from the transparent state. This causes a change in intensity of rubidium light transmitted through the vapor and serves as an indication of coincidence of the rubidium hyperfine frequency and the frequency of the microwave field. Changes in intensity of transmitted light are converted by a photocell into an electrical signal which, by means of an electronic integrating servo, is used to stabilize the five megacycle crystal oscillator from which the microwave field is derived.



*Rubidium Vapor Frequency Standard*

## GENERAL SPECIFICATIONS

Output Frequencies	5 mc, 1 mc and 100 kc, simultaneously. Other frequencies available on special order.
Output Level	5 mc and 1 mc: 1v rms into 50 ohms. 100 kc: 1v rms into 50 ohms, or minimum 3v into approximately 15,000 ohms, selected by internal switch.
Long-Term Stability	$5 \times 10^{-11}$ over any 1-year period (Standard Deviation).
Short-Term Stability	$1 \times 10^{-11}$ over a one-second averaging time (Standard Deviation).
Spectral Purity	Less than 2 cps bandwidth at 24 kmc when derived from 5 mc output.
Environmental Stability	Above long- and short-term stability specifications will be maintained over the following conditions: Temperature: 15° to 35°C Humidity: 0 to 95% Input voltage: $\pm 15\%$ of nominal Load: Open to short circuit
Accuracy and Frequency	Instrument is calibrated to any customer-specified time scale within $4 \times 10^{-8}$ of A.1, to an accuracy of $\pm 1 \times 10^{-10}$ relative to the U.S. Frequency Standard.
Fine Tuning Precision	Magnetic field tuning allows adjustment of frequency over a range of $+5 \times 10^{-9}$ to a setting precision of $1 \times 10^{-11}$ .
Stabilization Time	Instrument accuracy is $\pm 1 \times 10^{-10}$ after a two-hour warmup. Turn-off/turn-on repeatability $\pm 2 \times 10^{-11}$ after 12-hour warmup.
Crystal Oscillator Locking System	Crystal oscillator frequency is locked to the $Rb^{87}$ hyperfine frequency by an entirely electronic integrating servo having a d-c gain of approximately $10^8$ and a unity gain point of 70 cps.
Alarm Indicator	Front panel alarm light indicates visually that the output frequency is locked to the hyperfine transition frequency. Rear terminals connected to relay contacts provide for remote alarm systems.
Input Requirements	28v dc nominal, @ 2a.
Packaging	The frequency standard is housed in a cabinet accommodating a 19-inch panel. Cabinet dimensions are 21-7/16 inches wide x 12 7/8 inches high x 18 inches deep (2.9 cu. ft.). Total weight is approximately 95 pounds.

**PRICE:** \$15,900 f.o.b. Palo Alto, California. Terms: 30 days net.  
**DELIVERY:** 90 days from receipt of order.  
 (Price and delivery subject to change without notice)  
**ORDERING INFORMATION:** Please specify time scale when ordering.

## DESCRIPTION

A block diagram of the Alkali Vapor Frequency Standard System is shown below. The  $\text{Rb}^{87}$  vapor, whose hyperfine transition frequency is being monitored, is contained in a glass gas cell which in turn is housed in a microwave cavity. In order to obtain narrow spectral lines, a noble gas buffer is used to reduce the number of disorienting collisions of the rubidium atoms with the walls of the gas cell. In addition to giving narrow lines, these buffer gases cause a shift in the hyperfine frequency from its value of 6,834,682,614 cps. This pressure shift is utilized to simplify the problem of synthesizing the integral megacycle output frequency.

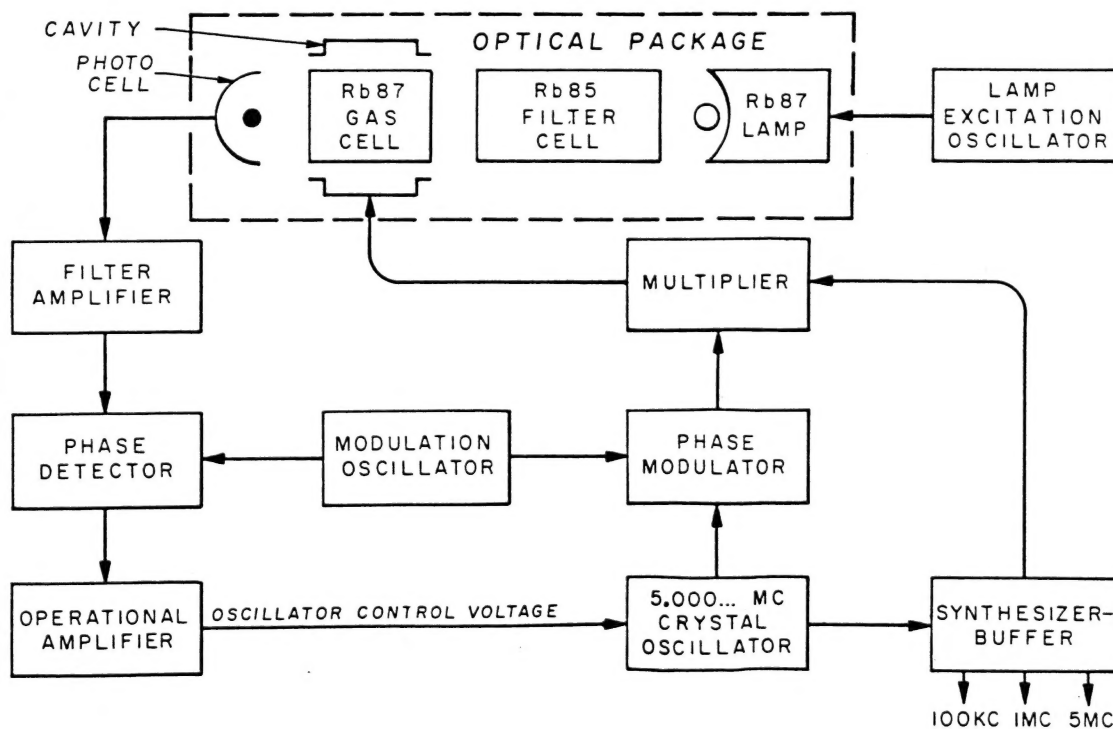
An important feature of the Rubidium Vapor Frequency Standard is the fact that the gas cell may be filled to give an integral megacycle output frequency on any preselected time scale. For example, the gas cell could be filled on the A.1 time scale for which the cesium hyperfine frequency is 9,192,631,770 cps, or on the current standard frequency broadcast offset of  $-130 \times 10^{-10}$  compared to A.1, or on the time scale used with the commercial cesium beam standard in which the cesium frequency under operating conditions is chosen to be 9,192,631,840 cps. More than one gas cell, each with its own pretuned cavity, may be supplied with the instrument, if it is desired to change from one time scale to another.

The resonant cavity which surrounds the gas cell is tuned to the hyperfine frequency and is excited by a phase modulated microwave signal. When the frequency of the resulting microwave magnetic field corresponds to the hyperfine frequency, transitions back to the optically opaque state are induced in the rubidium vapor resulting in a reduction of transmitted light.

The Varian Rubidium Vapor Frequency Standard contains two principal electronic subsystems. These are the totally electronic integrating servo for control of the local crystal oscillator, and the electronic frequency multiplying and synthesizing networks for multiplication of the local oscillator frequency up to the hyperfine frequency and for synthesis of the integral megacycle and other outputs.

A silicon solar cell is used to sense the level of light transmitted through the gas cell. The output of this solar cell contains a small a-c component which depends upon the relation of the frequency driving the cavity to the hyperfine frequency of the rubidium vapor. If the two frequencies are coincident, the transmitted light will be modulated at only second and higher harmonics of the modulation frequency. If the frequency of the microwave field is either higher or lower than the hyperfine frequency, a fundamental component of the modulation frequency will appear at the output. The phase of this component relative to the modulation frequency will depend upon the magnitude and sign of excursion from the hyperfine frequency.

In the phase detector, the phase of the optical output signal is compared with the phase of the modulation signal and the error signal is applied as a continuous correction to the five-megacycle crystal oscillator. This five-megacycle oscillator serves as the basic source for microwave energy to excite the cavity as well as a source for the various output frequencies. A frequency of 6834-13/19 mc is derived from the oscillator using a combination of multiplication and division, and the proper degree of buffer pressure shift is employed in the gas cell to bring the hyperfine frequency into coincidence with this synthesized frequency. Regenerative division and subsequent buffering provide the appropriate integral megacycle and 100-kc outputs.



*Rubidium Vapor Frequency Standard Block Diagram*